Effect of level of fiber of the rearing phase diets on egg production, digestive tract traits, and body measurements of brown egg-laying hens fed diets differing in energy concentration[1]

P. Guzmán, B. Saldaña, O. Bouali, L. Cámara, and G. G. Mateos

ABSTRACT This research studied the effects of additional fiber in the rearing phase diets on egg production, gastrointestinal tract (GIT) traits, and body measurements of brown egg-laying hens fed diets varying in energy concentration from 17 to 46 wk of age. The experiment was completely randomized with 10 treatments arranged as a 5 × 2 factorial with 5 rearing phase diets and 2 laying phase diets. During the rearing phase, treatments consisted of a control diet based on cereals and soybean meal and 4 additional diets with a combination of 2 fiber sources (cereal straw and sugar beet pulp, SBP) at 2 levels (2 and 4%). During the laying phase, diets differed in energy content (2,650 vs. 2,750 kcal AME_n/kg) but had the same amino acid content per unit of energy. The rearing diet did not affect any production trait except egg production that was lower in birds fed SBP than in birds fed straw (91.6 and 94.1%, respectively; $P < 0.05$). Laying hens fed the high energy diet had lower feed intake ($P < 0.001$), better feed conversion ($P < 0.01$), and greater BW gain ($P < 0.05$) than hens fed the low energy diet but egg production and egg weight were not affected. At 46 wk of age, none of the GIT traits was affected by previous dietary treatment. At this age, hen BW was positively related with body length (r = 0.500; $P < 0.01$), tarsus length (r = 0.758; $P < 0.001$), and body mass index (r = 0.762; $P < 0.001$) but no effects of type of diet on these traits were detected. In summary, the inclusion of up to 4% of a fiber source in the rearing diets did not affect GIT development of the hens but SBP reduced egg production. An increase in the energy content of the laying phase diet reduced ADFI and improved feed efficiency but did not affect any of the other traits studied.

Key words: energy content, gastrointestinal tract development, rearing diets, straw, sugar beet pulp

INTRODUCTION

Hen productivity is affected by numerous factors, including the physico-chemical characteristics of the diets fed during the rearing and the laying phases (Leeson and Summers, 2005; Pérez-Bonilla et al., 2012a). Pullets with a low BW at the onset of egg production produce fewer and smaller eggs than heavy pullets during the whole egg laying cycle (Leeson et al., 1997; Pérez-Bonilla et al., 2012a,b). Consequently, the implementation of strategies that favor feed intake during the rearing phase should result in an increase in BW gain (**BWG**) and in an improvement in hen productivity.

Dietary fiber has been considered traditionally as a diluent of poultry diets with negative effects on palatability and feed intake (Janssen and Carré, 1985; Mateos et al., 2002). However, recent studies have shown that the inclusion of moderate amounts of fiber in the diet might benefit the development of the gastrointestinal tract (**GIT**) and the production of HCl, bile acids, and endogenous enzymes (Hetland et al., 2005; González-Alvarado et al., 2008, 2010). In fact, dietary fiber often results in improved nutrient digestibility and growth in broilers (Sklan et al., 2003; Jiménez-Moreno et al., 2011, 2016) and pullets (Guzmán et al., 2015a,b). Mateos et al. (2012) suggested that the effects of additional fiber on poultry performance might depend on the type of fiber used, with more pronounced effects with the inclusion of insoluble fiber sources.

Before the start of the laying period, pullets need to adapt their GIT to the consumption of increased amounts of feed. A common commercial practice used by the industry to increase the digestive capacity of the bird consists in increasing the fiber content of the diets fed from 10 to 17 wk of age. However, the scientific information on the benefits of this practice on hen productivity is very limited.

The use of low energy laying diets might result in hens not being able to consume enough energy to satisfy their requirements for egg production, especially early in the egg production cycle, when the GIT is not yet well developed (Pérez-Bonilla et al., 2012b).

Consequently, the use of high energy diets in the laying phase might be more beneficial in hens that were fed low fiber diets during the rearing phase than in those that were fed high fiber diets because of differences in the development and physical capacity of the GIT.

Body measurements (body length, body mass index (**BMI**), tarsus length, and tarsus width) are useful criteria to predict the growth and future size of the birds (Senar and Pascual, 1997; Mendes et al., 2008; Cleasby et al., 2011) and the production potential of avian species (Ortiz et al., 2011; Saldaña et al., 2015a,b). However, the information available on the influence of nutritional practices during the rearing and production phases on these variables, and its relationship with BW and egg production of the laying hens is very limited.

The hypothesis tested in this research was that the inclusion of additional insoluble fiber, but not of soluble fiber, in the rearing phase diets could improve GIT development and subsequent production of the hens, especially at the onset of the egg cycle. Also, it was hypothesized that the use of high energy diets during the laying phase could be more beneficial in pullets that were fed low fiber diets during the rearing phase, because of the lower GIT capacity of these birds at 17 wk of age. This research evaluated the effects of the inclusion in the rearing phase diets of 2 fiber sources differing in their physico-chemical characteristics, and the energy concentration of the laying phase diets on production, egg quality, GIT traits, and body measurements of brown egg-laying hens from 17 to 46 wk of age.

MATERIALS AND METHODS

All experimental procedures were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007).

Husbandry, Diets, and Experimental Design

Details on diet composition and bird management from hatching to 17 wk of age have been reported elsewhere (Guzmán et al., 2015b). Briefly, 2,500 recently hatched Lohmann Brown Classic pullets were placed in an environmentally controlled barn, in groups of 50, in 50 cages with similar initial average BW. During the rearing phase, the diets of the 3 feeding periods (one to 5 wk, 5 to 10 wk, and 10 to 17 wk of age) were arranged as a 1 + (2 × 2) factorial with a control diet based on corn and soybean meal and 4 additional diets, which resulted from the combination of including 2 fiber sources differing in physico-chemical properties (straw and sugar beet pulp; **SBP**) at 2 levels (2 and 4%). The fiber sources were included in their respective diets at the expense (wt/wt) of the whole control diet.

At 17 wk of age (start of the laying phase), pullets were moved to an environmentally controlled barn and placed in enriched cages (40 cm × 80 cm × 68 cm; Facco S.p.A., Padova, Italy) equipped with an open trough feeder and 2 low pressure nipple drinkers. Because of the number and dimensions of the layer cages and the lack of space in the experimental barn, only 8 out of the 10 replicates of each of the previous treatments and 10 out of 16 pullets of each rearing cage, chosen at random, were used. All the remaining birds were discarded. The pullets were placed in the layer cages according to previous treatment, without any commingling. Consequently, all the hens in each of the laying cages belonged to the same cage used during the rearing phase. Half of the cage replicates (n = 4) of each of the previous rearing treatments received a low energy layer diet (2,650 kcal AME_n/kg) and the other half received a higher energy layer diet (2,750 kcal AME_n/kg). Both diets met or exceeded the nutrient requirements for brown egg-laying hens (FEDNA, 2008) and had the same AME_n to indispensable amino acids (**AA**) ratio (Table 1). Feed in mash form and water were provided for ad libitum consumption. The experiment lasted for 7 periods of 4 wk, with the exception of the first period that lasted 5 wk (17 to 22 wk). The longer length of the first period was planned to equalize egg production of the young hens fed different diets during the rearing period. Hens were vaccinated against main diseases and managed according to commercial practices (Lohmann, 2013). The light program consisted of 13 h for the first wk, then increased one h per wk until reaching 16 h at 20 wk of age, and kept constant to the end of the experiment. The temperature inside the barn was recorded daily and varied, as an average, from 26 ± 3°C in June (first period of the experiment) to 21 ± 3°C in January (last period of the experiment).

The experimental design was completely randomized with 10 diets arranged as a 5 × 2 factorial with 5 rearing phase diets and 2 laying phase diets. The 5 rearing phase diets consisted of a control diet and the combination of 2 fiber sources (straw and SBP) at 2 levels of inclusion (2 and 4%). The 2 laying phase diets differed in energy content (2,650 vs. 2,750 kcal AME_n /kg).

Hen Productivity and Egg Quality

Egg production was measured daily by replicate. All the eggs laid the last 2 d of each wk were weighed by replicate and the average value of the 4 wk (or 5 wk for the first period) was used to estimate the average weight for each of the 7 experimental periods. Feed disappearance was recorded per replicate by period and for the entire experiment. In addition, the hens were weighed by replicate at the start of the experiment and at the end of each of the 7 experimental periods. Any mortality was recorded and weighed as it occurred. From these data, egg production, egg weight, egg mass, ADFI, feed conversion ratio per kilogram and per dozen of eggs,

Table 1. Ingredient composition and calculated analysis (% as fed bases) of the experimental diets.

	AME$_n$ (kcal/kg)	
	2,650	2,750
Ingredient		
Wheat	40.0	40.0
Yellow corn	20.0	17.0
Soybean meal (47% CP)	17.1	18.0
Sunflower meal (34% CP)	10.3	11.0
Sunflower oil soapstock	1.45	3.39
Dicalcium phosphate	1.08	1.18
Calcium carbonate	8.24	8.50
Sodium chloride	0.28	0.30
DL-methionine (99%)	0.11	0.13
Sepiolite[1]	0.94	-
Vitamin and mineral premix[2]	0.50	0.50
Calculated analysis[3]		
DM	89.4	89.8
AME$_n$ (kcal/kg)	2,650	2,750
CP	17.6	18.2
Digestible amino acids		
Lys	0.68	0.71
Met	0.37	0.40
Met+cys	0.63	0.66
Thr	0.53	0.55
Trp	0.18	0.19
Crude fiber	4.4	4.6
Neutral detergent fiber	11.1	11.4
Ash	12.4	12.9
Sodium	0.14	0.14
Calcium	3.75	3.85
Total phosphorus	0.61	0.64
Digestible phosphorus	0.35	0.37

[1]A complex magnesium silicate clay incorporated as an inert material.

[2]Provided the following (per kilogram of diet): vitamin A (*trans*-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3,750 IU; vitamin E (dl-α-tocopheryl acetate), 10 mg; vitamin B_1, 1.3 mg; vitamin B_2, 5 mg; vitamin B_6, 1.8 mg; vitamin B_{12} (cyanocobalamin), 13 mg; niacin, 25 mg; pantothenic acid (d-calcium pantothenate), 10 mg; folic acid, 1.3 mg; biotin, 1.3 mg; choline (choline chloride), 250 mg; manganese (MnO), 88 mg; zinc (ZnO), 63 mg; iron ($FeSO_4$ H_2O), 38 mg; copper ($CuSO_4$ $5H_2O$), 8 mg; iodine [$Ca(IO_3)_2$], 0.6 mg; selenium (Na_2SeO_3), 0.4 mg; 6-phytase (EC 3.1.3.26) 375 FTU/kg; endo-1,3-β-xylanase (EC 3.2.1.8), 190 UI/g, endo-1,4(4)-β-glucanase (EC 3.2.1.6), 610 U/g; etoxiquin, 200 mg.

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

Table 2. Determined chemical analysis[1] and particle size distribution[2] of the laying phase diets (% as fed basis, unless otherwise indicated).

	2,650 kcal AME$_n$/kg	2,750 kcal AME$_n$/kg
Chemical analyses		
Gross energy (kcal/kg)	3,848	3,872
DM	90.0	89.5
CP	18.2	18.5
Indispensable amino acids		
Lys	0.82	0.84
Met	0.41	0.43
Met+cys	0.74	0.75
Thr	0.66	0.67
Trp	0.21	0.22
Ether extract	5.4	6.8
Linoleic acid	1.9	2.7
Total ash	13.0	13.3
Particle size[3] (μm)		
2,500	11.70	12.86
1,250	37.41	35.91
630	28.21	29.95
315	17.90	15.01
160	4.75	6.16
80	0.03	0.11
GMD[4] ± GSD[5]	1,119± 2.06	1,124± 2.10

[1]Analyzed in duplicate.

[2]Sieve diameter (μm).

[3]The percentage of particles bigger than 2,500 μm or smaller than 80 μm was negligible.

[4]Geometric mean diameter.

[5]GSD = Log normal SD.

and BWG were calculated by period and cumulatively. In addition, the number of dirty, broken, and shell-less eggs was recorded daily by replicate in all eggs produced. An egg was considered as dirty when a spot of any kind or size was detected on the shell (Lázaro et al., 2003). Other egg quality traits, including Haugh units, yolk and shell color, shell strength, and shell thickness, were measured in 12 fresh eggs collected randomly from each replicate for the last 2 d of the 7 experimental periods. Haugh units and yolk color (Roche color fan) were measured in fresh eggs using a multitester equipment (QCM System, Technical Services and Supplies, Dunnington, York, UK) as indicated by Safaa et al. (2009). Shell color was measured using a Minolta colorimeter (Chroma Meter Model CR-200, Minolta Corp., Ramsey, NJ) and the Hunter values, L* (lightness), a* (green to red), and b* (blue to yellow) were recorded. Eggshell strength (kg/cm^2) was evaluated applying increased pressure to the broad pole of the egg using a press meter (Egg Force Reader, SANOVO Technology A/S, Odense, Denmark), as indicated by Safaa et al. (2008a). Shell thickness was measured at the 2 pole ends and at the middle section of the egg, using a digital micrometer (model IT-014UT, Mitotuyo, Kawasaki, Japan). The average of the 3 measurements per egg was used for further analyses.

Digestive Traits and Body Measurements

At 46 wk of age, after the corresponding control on hen productivity, 2 hens per replicate were randomly selected, weighed individually, and euthanized by CO_2 inhalation. The full GIT, from the beginning of the proventriculus to the cloaca, including the spleen, liver, and pancreas, but not the crop and the esophagus, was removed aseptically and weighed. Liver, proventriculus, and gizzard were excised and weighed, and the results expressed relative to BW (%). Then, the gizzard was emptied of any digesta, cleaned, dried with desiccant paper, and weighed again. The fresh digesta content was measured as the difference between the full and empty gizzard weight and expressed relative (%) to the weight of the full organ. The pH of the gizzard was measured in duplicate in situ using a digital pH meter fitted with a fine tip glass electrode (model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jiménez-Moreno et al. (2009) and the mean value was used for further evaluation. The length of the duodenum (from the end of the gizzard to pancreo-biliary ducts), jejunum (from pancreo-biliary ducts to Meckel's diverticulum), ileum (from Meckel's diverticulum to ileo-cecal

Table 3. Influence of type of pullet diet and energy content of the laying diet (kcal AME_n /kg) on productive performance of the hens from 17 to 46 wk of age.

	Egg production (%)	ADFI (g/hen)	Egg weight (g)	Egg mass (g/d)	Feed conversion ratio (kg:kg)	Feed conversion ratio (kg:dozen)	BW (g) 17 wk	BW (g) 46 wk	BW gain (g)
Laying diet									
2,650 kcal/kg	93.4	114.6[a]	61.9	57.7	1.99[a]	1.48[a]	1,453	1,792	340[b]
2,750 kcal/kg	92.7	111.3[b]	62.0	57.5	1.94[b]	1.44[b]	1,442	1,821	379[a]
Pullet diet									
Control	93.9	113.8	62.2	58.4	1.95	1.46	1,467	1,844	376
Straw, 2%	94.0	113.1	61.9	58.1	1.95	1.44	1,451	1,801	350
Straw, 4%	94.0	113.7	61.5	57.8	1.97	1.45	1,455	1,815	359
Sugar beet pulp, 2%	91.9	111.9	62.5	57.5	1.95	1.47	1,447	1,783	336
Sugar beet pulp, 4%	91.5	112.4	61.6	56.4	2.00	1.47	1,417	1,791	375
Main effects, pullet diet									
Fiber source									
Straw	94.1[a]	113.4	61.6	57.9	1.96	1.45	1,453	1,808	355
SBP	91.6[b]	112.1	62.1	56.9	1.97	1.47	1,432	1,788	356
Fiber level									
2%	92.9	112.5	62.2	57.8	1.95	1.45	1,449	1,792	343
4%	92.7	113.1	61.6	57.1	1.98	1.46	1,436	1,803	367
SD[1]	2.60	2.52	0.28	1.76	0.052	0.042	45.9	56.6	49.2
				Probability[2]					
Laying diet	0.401	0.001	0.690	0.676	0.008	0.016	0.481	0.117	0.017
Pullet diet	0.107	0.433	0.463	0.210	0.367	0.582	0.272	0.259	0.448
Contrast									
Fiber source in pullet diets	0.012	0.147	0.414	0.114	0.427	0.138	0.198	0.315	0.957
Fiber level in pullet diets	0.809	0.494	0.153	0.261	0.228	0.489	0.425	0.593	0.179

[a,b]Means with different superscripts are significantly different ($P < 0.05$).
[1]Standard deviation (20 replicates for each laying diet, 8 replicates for each pullet diet, and 16 replicates for fiber source and fiber level).
[2]The interactions between pullet and laying diets and between source and level of fiber of the pullet diets were not significant ($P > 0.05$).

junction), and the two ceca (from the ostium to the tip of the right and left ceca) was measured on a glass surface using a flexible tape with a precision of one mm and expressed relative to live BW (cm/kg BW). The length of the small intestine (**SI**) was determined by adding the length of the duodenum, jejunum, and ileum. Body length of the hens was measured from the tip of the beak to the end of the longest phalanx with the same flexible tape used for SI measurements. Tarsus length and tarsus width, measured in the middle point of the bone, were determined using a digital caliper. In addition, the BMI was estimated by dividing the BW (g) of the hen by the body length^2 (cm), as indicated by Mendes et al. (2007). The average value of the 2 hens per replicate was used for further statistical analysis of all the traits studied.

Laboratory Analyses

The determined chemical analyses of the rearing phase diets have been reported elsewhere (Guzmán et al., 2015b). Representative samples of the laying hen diets were ground in a laboratory mill (Model Z-I, Retsch Stuttgart, Germany) equipped with a one-mm screen and analyzed for moisture by oven-drying (method 930.15), total ash using a muffle furnace (method 942.05), and nitrogen by Dumas (method 968.06) using a Leco analyzer (Model FP-528, Leco Corp., St. Joseph, MI) as described by AOAC International (2005). Ether extract was determined by Soxhlet analysis after 3N HCl acid hydrolysis (Boletín Oficial del Estado, 1995) and gross energy using an adiabatic bomb calorimeter (Model 1356, Parr Instrument Company, Moline, IL). The AA content of the diets was determined by ion-exchange chromatography (Hewlett-Packard 1100, Waldbronn, Germany) as described by De Coca-Sinova et al. (2008) and the linoleic acid as indicated by Grobas et al. (1999a). The particle size distribution and the geometric mean diameter of the diets were determined in 100 g samples using a shaker (Retsch, Stuttgart, Germany) equipped with 8 sieves ranging in mesh from 5,000 to 40 μm as outlined by the ASAE (1995). All the analyses were conducted in duplicate, except for particle size distribution that was conducted in triplicate. The determined physico-chemical analyses of the diets are shown in Table 2.

Statistical Analysis

Data were analyzed as a completely randomized design by 2-way ANOVA using the GLM procedure of SAS (SAS Institute, 2004). Main effects (rearing and laying phase diets) and the interactions between main effects were analyzed. Because 4 of the rearing phase diets were arranged as a 2 × 2 factorial, the main effects (fiber source and fiber level) and the interactions between these 2 main effects also were studied. The experimental unit was the cage for all measurements. Differences were considered significant at $P < 0.05$. Results in tables are presented as means. In addition, the Pearson correlation analyses (SAS Institute, 2004)

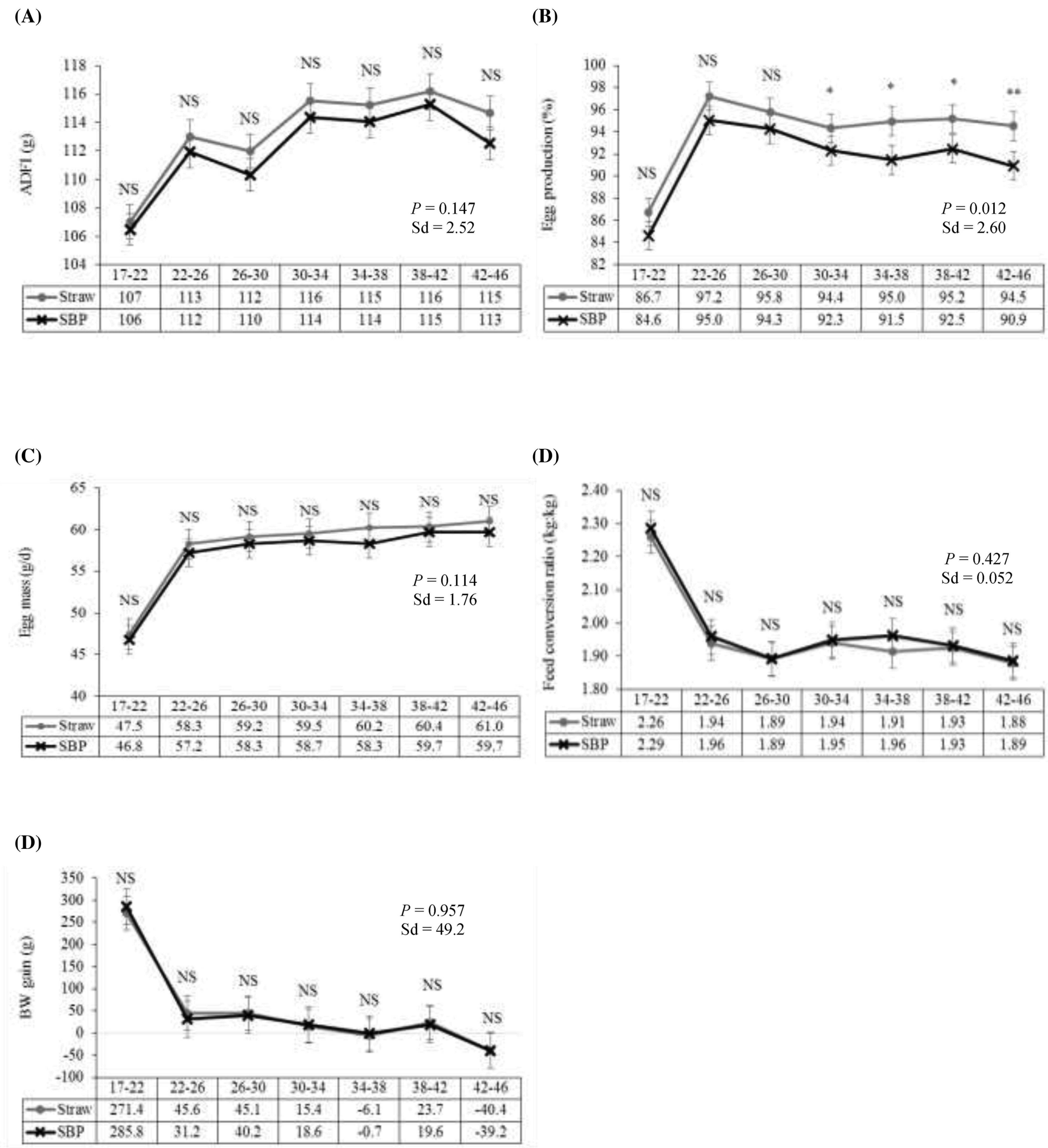

Figure 1. Effect of type of fiber (straw vs. sugar beet pulp; SBP) used in the rearing phase diets on ADFI (A), egg production (B), egg mass (C), feed conversion ratio per kilogram of eggs (D), and BW gain (E) of the hens by period from 17 to 46 wk of age (n = 16). NS = $P \geq 0.05$, $^{*}P \leq 0.05$, and $^{**}P \leq 0.01$.

were conducted to study the relation between BW and BMI, body length, tarsus length, and tarsus width of the hens at 46 wk of age.

RESULTS

Hen Productivity and Egg Quality Traits

Mortality during the laying period was 1.8% and was not related to treatment (data not shown). No interactions between the rearing and the laying phase diets were detected for any of the traits studied and, therefore, only main effects are presented. Source and level of fiber of the rearing phase diets did not affect any of the production variables studied, except egg production that was lower in hens fed SBP during the rearing phase than in hens fed straw (91.6 vs. 94.1%: $P < 0.05$; Table 3). The negative effects of the inclusion of SBP in the pullet diets on hen performance were more noticeable in the last periods of the laying phase (Figure 1). Egg production was not affected by the level of fiber of the pullet diets in any of the periods considered (Figure 2).

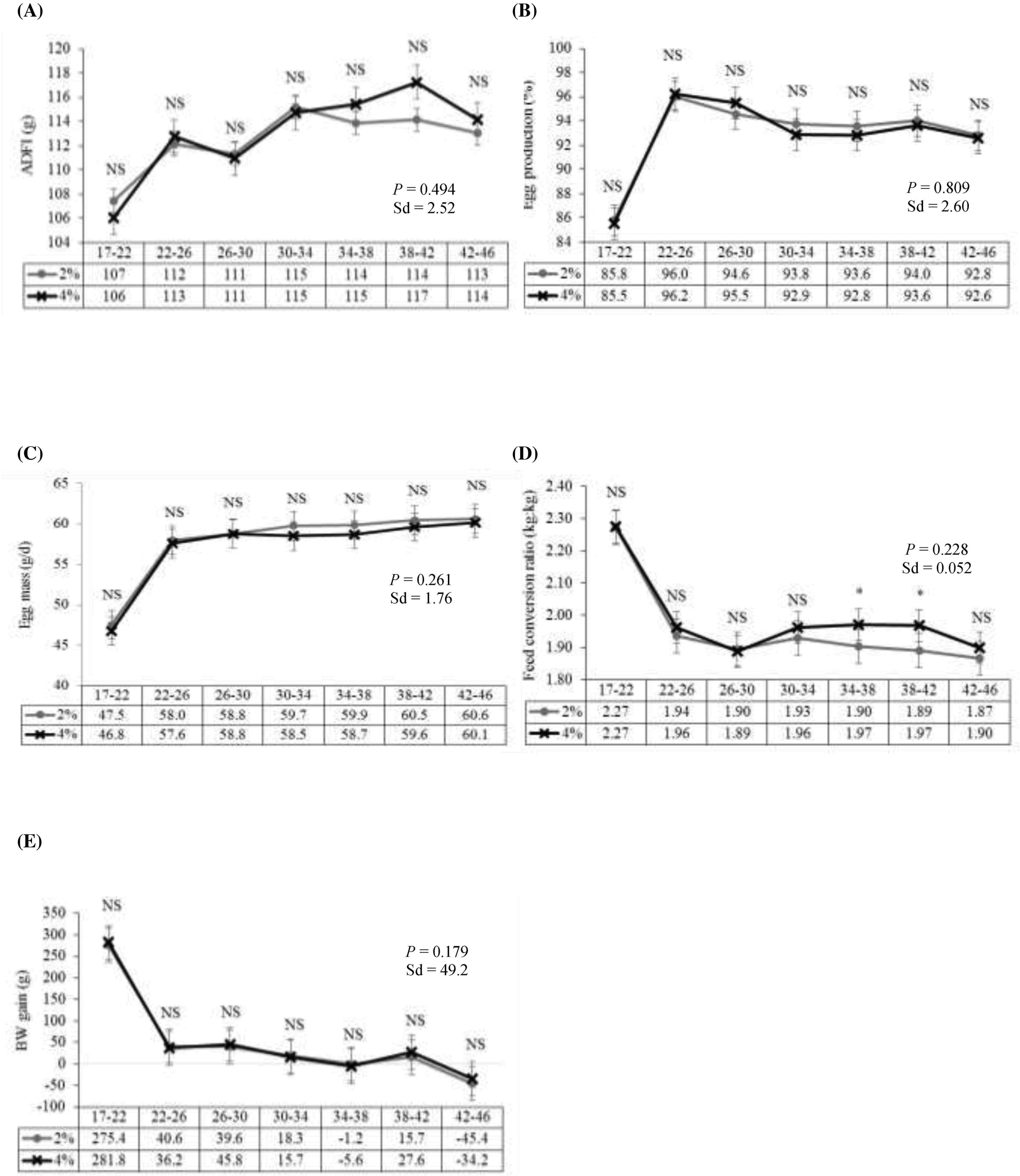

Figure 2. Effect of level of fiber inclusion (2 vs. 4%) in the rearing phase diets on ADFI (A), egg production (B), egg mass (C), feed conversion ratio per kilogram of eggs (D), and BW gain (E) of the hens by period from 17 to 46 wk of age (n = 16). NS = $P \geq 0.05$ and $^{*}P \leq 0.05$.

For the entire laying period, a 3.6% decrease in the energy content of the diet (2,750 vs. 2,650 kcal AME_n/kg) increased ADFI by 3.0% (111.3 vs. 114.6 g; $P < 0.001$), worsened feed conversion ratio per kilogram of eggs by 2.6% (1.94 vs. 1.99; $P < 0.01$), and decreased BWG of the hens by 10.3% (379 vs. 340 g; $P < 0.05$). However, egg production, egg weight, and egg mass were not affected. Data on the effects of energy content of the laying diet on egg production by period are shown in Figure 3.

Egg quality traits were not affected by the type of diet fed during the pullet or the laying phase in any of the periods studied (Table 4).

Digestive Tract Traits and Body Measurements

At 46 wk of age, the relative weight of the organs of the GIT and of the fresh digesta content and pH of the gizzard were not affected by the type of pullet or

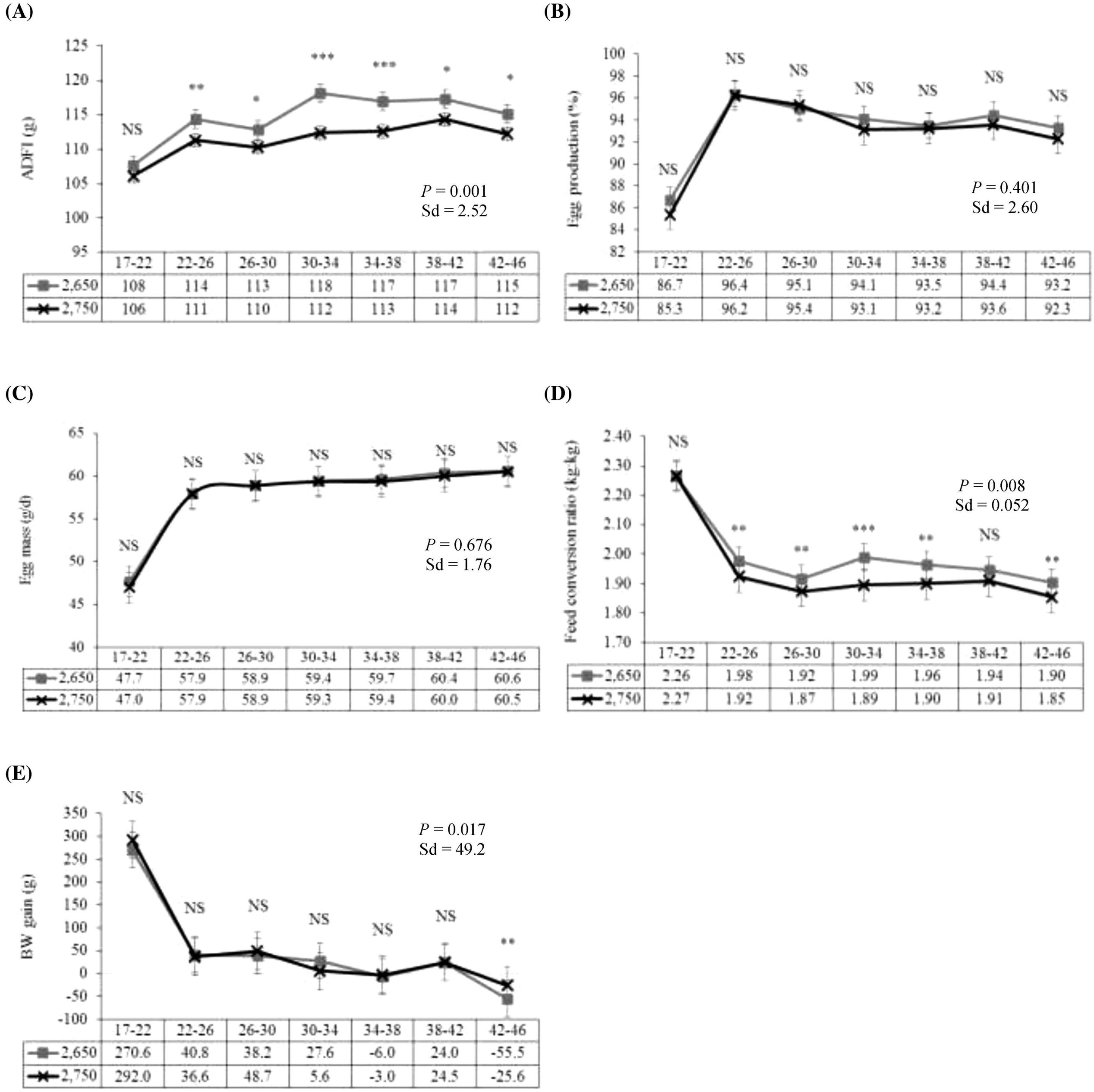

Figure 3. Effect of energy content of the laying phase diets (2,650 vs. 2,750 kcal AME_n/kg) on ADFI (A), egg production (B), egg mass (C), feed conversion ratio per kilogram of eggs (D), and BW gain (E) of the hens by period from 17 to 46 wk of age (n = 20). NS = $P \geq 0.05$, $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, and $^{***}P \leq 0.001$.

layer diet used (Table 5). Neither the relative length of the SI and cecum nor the body and tarsus length was affected by dietary treatment (Table 6). Significant correlations between BW of the hens and BMI (r = 0.762; $P < 0.001$), body length (r = 0.500; $P < 0.01$), and tarsus length (r = 0.758; $P < 0.001$) were detected at this age (Table 7).

DISCUSSION

Hen Productivity and Egg Quality

From 17 to 46 wk of age, hen performance was not affected by the inclusion of fiber in the pullet diets, except for egg production that was significantly lower in hens fed SBP than in hens fed straw. The authors have not found any published research on the effects of the inclusion of SBP in the rearing diets on egg production to compare with the results reported herein, and we do not have any clear explanation for these results. Pullets fed SBP during the rearing phase were 1.5% lighter at 17 wk of age and had 1.2% lower ADFI during the laying phase than hens fed straw, although the differences were not significant. Probably, the combined effect of lighter BW at the onset of egg production and reduced ADFI early in the egg cycle resulted in lower egg production in these pullets (Leeson et al., 1997; Pérez-Bonilla et al., 2012a). In this respect, Almirall

Table 4. Influence of source and level of fiber of the rearing phase diets (hatching to 17 wk) and of the AME_n (kcal/kg) of the laying phase diet on egg quality from 17 to 46 wk of age.

	Dirty eggs (%)	Haugh Units	RCF[1]	Undergrades[2] (%)	Shell quality Strength (kg/cm^2)	Thickness (mm)	Color[3] L	A	B
Laying diet									
2,650 kcal/kg	2.51	90.9	10.4	0.781	5.09	0.381	61.4	15.5	32.6
2,750 kcal/kg	2.67	90.7	10.4	0.838	5.15	0.383	61.7	15.3	32.7
Pullet diet									
Control	2.74	90.8	10.5	0.919	5.07	0.378	62.1	15.1	32.6
Straw, 2%	2.50	91.0	10.4	0.962	5.07	0.384	61.1	15.7	32.8
Straw, 4%	2.75	90.8	10.4	0.736	5.21	0.381	61.6	15.3	32.5
Sugar beet pulp, 2%	2.64	91.0	10.5	0.665	5.03	0.382	61.3	15.5	32.8
Sugar beet pulp, 4%	2.33	90.5	10.5	0.765	5.22	0.383	61.2	15.6	32.4
Main effects, pullet diet									
Fiber source									
Straw	2.62	90.9	10.3	0.849	5.14	0.383	61.4	15.5	32.6
SBP	2.48	90.8	10.4	0.715	5.12	0.383	61.2	15.5	32.6
Fiber level									
2%	2.57	91.0	10.4	0.814	5.05	0.383	61.2	15.6	32.8
4%	2.54	90.7	10.3	0.750	5.22	0.382	61.4	15.4	32.5
SD[4]	0.812	1.38	0.35	0.2918	0.380	0.0088	1.08	0.72	0.70
				Probability[5]					
Laying diet	0.532	0.794	0.928	0.537	0.654	0.831	0.362	0.261	0.721
Pullet diet	0.820	0.942	0.951	0.229	0.760	0.693	0.436	0.564	0.805
Contrast									
Fiber source in pullet diets	0.625	0.751	0.532	0.209	0.916	0.984	0.757	0.714	0.822
Fiber level in pullet diets	0.919	0.456	0.677	0.548	0.208	0.858	0.637	0.543	0.227

[1]Roche color fan.
[2]Obtained as the addition of broken and shell-less eggs.
[3]A high L value means lighter color; a high A value means redder color, and a high B value means a more yellow color.
[4]Standard deviation (20 replicates for each laying diet, 8 replicates for each pullet diet, and 16 replicates for fiber source and fiber level).
[5]The interactions between pullet and laying diets and between source and level of fiber of the pullet diets were not significant ($P > 0.05$).

et al. (1997) reported a reduction in egg production in hens fed a cereal-soybean meal diet diluted with 7.5 or 15.0% SBP, although in this research all hens received a common feeding program during the rearing phase. Similar reduction in BWG and feed efficiency has been reported in broilers by González-Alvarado et al. (2010) and Sadeghi et al. (2015) with the inclusion of 3% SBP in the diet. Sadeghi et al. (2015) reported also an increase in intestinal viscosity and a reduction in villus height of the duodenum and ileum mucosa when 3% SBP was included in the diet. The fiber fraction of SBP is more soluble than that of straw (Brøkner et al., 2012; Bach Knudsen, 2014). Story and Kritchersky (1982) reported that the soluble part of the fibrous fraction might interfere with the metabolism of the lipid (Forman and Schneeman, 1980; Anderson et al., 1994) and other dietary fractions (Pettersson and Razdan, 1993; Razdan and Pettersson, 1994), causing a reduction in egg production.

From 17 to 46 wk of age, egg production was high in all hens, irrespective of the energy concentration of the diet, in agreement with data of Grobas et al. (1999a,b) comparing diets with 2,680 and 2,810 kcal AME_n/kg and Saldaña et al. (2013) comparing diets with 2,650 and 2,750 kcal/kg in brown egg-laying hens. Similar data have been reported by Jalal et al. (2006) and Murugesan and Persia (2013) in Single Comb White Leghorn hens fed diets containing 2,800 to 2,900 kcal AME_n/kg. In contrast, Pérez-Bonilla et al. (2012b) observed an increase in egg production from 88.8 to 91.2% as the AME_n concentration of the diet increased from 2,650 to 2,750 kcal/kg. In the research of Pérez-Bonilla et al. (2012b), the hens ingested 3.0% more energy when the high energy diet was used, which might justify the increase in egg production observed. However, in the current research, hens compensated for the lower energy content of the diet by increasing feed intake proportionally and consequently, no differences in egg production were expected.

Egg weight was not affected by energy concentration of the diet, in agreement with data of Çiftci et al. (2003), Jalal et al. (2006), and Murugesan and Persia (2013). In contrast, Harms et al. (2000), Wu et al. (2007), and Bouvarel et al. (2010) reported that egg weight increased as the AME_n content of the diet increased. Under practical conditions, egg size depends primarily of the methionine, fat, and linoleic acid content of the diet (Safaa et al., 2008b). As the energy concentration of the diet increases, the level of supplemental fat and linoleic acid are often increased, which may result in heavier eggs (Grobas et al., 1999c; Pérez-Bonilla et al., 2011). The methionine, linoleic acid, and fat content of the diets used in the current research, however, were above requirements (NRC, 1994; FEDNA, 2008) and, consequently, no differences in egg weight between treatments should be expected.

An increase of 100 kcal of AME_n/kg diet resulted in an increase in BW of the hens of 0.18 g/d, a value

Table 5. Influence of source and level of fiber of the rearing phase diets (hatching to 17 wk) and energy content (kcal AME_n/kg) of the laying phase diets on BW, the relative digestive organ weight (% BW), and gizzard traits of laying hens at 46 wk of age.

					Gizzard traits			
	BW (g)	GIT (%)	Liver (%)	Proventriculus[1] (%)	Weight[1] (g)	Weight[1] (%)	Content (%)	pH
Laying diet								
2,650 kcal/kg	1,861	12.5	2.61	0.551	51.6	2.78	33.3	4.04
2,750 kcal/kg	1,827	12.5	2.70	0.560	49.5	2.71	32.2	4.01
Pullet diet								
Control	1,872	12.2	2.65	0.512	49.9	2.66	34.3	4.08
Straw, 2%	1,810	12.5	2.73	0.555	50.8	2.81	32.6	4.01
Straw, 4%	1,878	12.6	2.57	0.565	53.3	2.86	31.5	4.00
Sugar beet pulp, 2%	1,841	12.8	2.66	0.554	49.7	2.70	30.9	4.17
Sugar beet pulp, 4%	1,811	12.8	2.65	0.590	50.4	2.79	32.5	4.06
Main effects, pullet diet								
Fiber source								
Straw	1,843	12.5	2.65	0.560	52.1	2.83	32.0	4.00
SBP	1,826	12.7	2.66	0.572	50.0	2.74	31.7	4.11
Fiber level								
2%	1,825	12.6	2.69	0.555	50.2	2.75	31.7	4.09
4%	1,844	12.6	2.61	0.577	51.8	2.82	32.0	4.02
SD[2]	137.2	0.69	0.248	0.0990	6.12	0.257	3.89	0.281
				Probability[3]				
Laying diet	0.680	0.676	0.118	0.829	0.454	0.446	0.438	0.653
Pullet diet	0.774	0.453	0.595	0.659	0.763	0.569	0.500	0.726
Contrast								
Fiber source in pullet diets	0.717	0.436	0.912	0.770	0.351	0.343	0.806	0.260
Fiber level in pullet diets	0.691	0.922	0.230	0.571	0.471	0.485	0.866	0.538

[1]With contents.
[2]Standard deviation (20 replicates for each laying diet, 8 replicates for each pullet diet, and 16 replicates for fiber source and fiber level).
[3]The interactions between pullet and laying diets and between source and level of fiber of the pullet diets were not significant ($P > 0.05$).

that was within the range of 0.08 to 0.45 g/d reported by others (Grobas et al., 1999a; Harms et al., 2000; Pérez-Bonilla et al., 2012b). Body weight gain and egg mass production of the hens depends on their genetic background. When birds are fed low energy diets, they might not be able to consume enough feed to keep their energy intake constant, resulting in a reduction in BW (Nielsen, 2004; Pérez-Bonilla et al., 2012b). On the other hand, when hens are fed diets with a high energy content, they over consume energy, which might be stored as body fat rather than used for extra increases in egg mass, leading to moderate increases in BWG (Pérez-Bonilla et al., 2012b). The higher BWG of the hens fed the high energy diet might be also a consequence of the higher level of supplemental fat (1.4 vs. 3.4%) of this diet.

Egg quality traits were not affected by the energy content of the layer diet, in agreement with data of Grobas et al. (1999c), Junqueira et al. (2006), and Saldaña et al. (2013). In contrast, Wu et al. (2005) and Pérez-Bonilla et al. (2012b) reported a linear decrease in albumen quality as the energy concentration of the diet increased. In the research of Wu et al. (2005) diets were not iso-aminoacidic per unit of energy, and the intake in indispensable AA was lower when fed the high energy diet than when fed the low energy diet, which might have affected albumen quality. Also, the high energy diet used by Pérez-Bonilla et al. (2012b) had more fat and wheat and less barley than the low energy diet. In the current research, however, AA intake and the ingredient composition of the diets were similar for both groups of hens. Consequently, no differences in egg quality traits should be expected.

Digestive Tract Traits and Body Measurements

Fiber inclusion affects GIT development in both broilers (Jiménez-Moreno et al., 2010; Sadeghi et al., 2015) and pullets (Guzmán et al., 2015b). Dietary fiber increases the retention time of the digesta in the proximal part of the GIT of young birds, improving gizzard weight and function (Frikha et al., 2009; Jiménez-Moreno et al., 2013) and increasing the relative length of the SI (Van der Klis and Van Vorst, 1993; Guzmán et al., 2015b). These changes in GIT development might result in an increase in the capacity for feed ingestion during the start of the laying period. At 46 wk of age, however, none of the GIT traits studied was affected by the characteristics of the pullet diets. The authors have not found any published report on the effects of fiber content of the rearing phase diets on GIT traits at the end of the laying period. The data presented herein indicate that the potential beneficial effects of dietary fiber on the size and development of the GIT are not long-lasting and disappear once the birds are fed a common commercial layer diet (Mateos et al., 2012). In this respect, Saldaña et al. (2013) reported similar size and development of the different organs of the GIT

Table 6. Influence of source and level of fiber of the rearing phase diets (from hatching to 17 wk) and of the AME_n (kcal/kg) of the laying phase diet on body mass index (BMI, g BW/length cm^2), relative lengths (cm/kg BW[1]) of the hen, tarsus, small intestine (SI) and cecum, and relative width (cm/kg BW) of the tarsus at 46 wk of age.

		Relative length							
	BMI	Tarsus	Body	Duodenum	Jejunum	Ileum	SI[2]	Cecum	Tarsus relative width
Laying diet									
2,650 kcal/kg	0.432	5.47	35.5	13.9	42.0	38.4	94.3	12.4	0.702
2,750 kcal/kg	0.431	5.50	35.9	13.9	42.2	37.9	94.0	12.3	0.701
Pullet diet									
Control	0.444	5.40	34.8	13.9	41.2	37.5	92.5	12.0	0.688
Straw, 2%	0.419	5.55	36.4	13.6	42.0	37.9	93.4	12.9	0.709
Straw, 4%	0.429	5.45	35.4	14.6	41.7	38.7	94.9	12.5	0.694
Sugar beet pulp, 2%	0.431	5.47	35.8	13.6	42.8	38.1	94.4	12.1	0.697
Sugar beet pulp, 4%	0.435	5.55	35.9	13.9	43.5	39.3	96.7	12.6	0.718
Main effects, pullet diet									
Fiber source									
Straw	0.424	5.50	35.9	14.1	41.8	38.2	94.1	12.7	0.702
SBP	0.433	5.51	35.8	13.7	43.1	38.7	95.5	12.3	0.708
Fiber level									
2%	0.425	5.51	36.1	13.6	42.4	37.9	93.9	12.4	0.703
4%	0.432	5.50	35.6	14.2	42.6	39.0	95.8	12.5	0.706
SD[3]	0.0296	0.339	2.48	1.65	3.52	3.45	5.15	3.68	0.0487
					Probability[4]				
Laying diet	0.836	0.821	0.881	0.932	0.757	0.545	0.885	0.856	0.878
Pullet diet	0.602	0.899	0.763	0.729	0.589	0.854	0.818	0.851	0.746
Contrast									
Fiber source in pullet diets	0.455	0.706	0.963	0.455	0.237	0.735	0.589	0.612	0.706
Fiber level in pullet diets	0.527	0.926	0.616	0.267	0.859	0.415	0.467	0.895	0.918

[1]The BW is shown in Table 5.
[2]Small intestine was calculated based on the data of duodenum, jejunum, and ileum.
[3]Standard deviation (20 replicates for each laying diet, 8 replicates for each pullet diet, and 16 replicates for fiber source and fiber level).
[4]The interactions between pullet and laying diets and between source and level of fiber of the pullet diets were not significant ($P > 0.05$).

Table 7. Correlations between BW[1] and body length, tarsus length, tarsus width, and body mass index (BMI) of the hens at 46 wk of age.

	Body length (cm)	Tarsus length (cm)	Tarsus width (cm)	BMI (g/cm^2)
r	0.500	0.758	0.295	0.762
Probability	0.001	<.001	0.064	<.001

[1]Average of 2 hens per replicate. The average BW of the hens used is shown in Table 5.

in 46-week-old hens that were fed mash or crumble diets during the rearing phase, consistent with the results reported herein. Also, Saldaña et al. (2015a) reported that the effects of fed form on the GIT traits of pullets from zero to 17 wk of age, reverted quickly when the birds were changed from receiving crumbles to receiving mash diets.

Body length, BMI, and tarsus measurements are useful criteria to evaluate body size and composition of avian species, such as sparrows (Cleasby et al., 2011), broilers (Mendes et al., 2007; Van Roovert-Reijrink, 2013), pullets (Lamazares et al. 2006; Ortiz et al. 2011), and hens (Ojedapo et al., 2012). In the current research, an increase in the fiber content of the rearing diets or in the energy of the laying hen diets had no effects on these traits at 46 wk of age. Similarly, Saldaña et al. (2013) did not find any difference in body length or tarsus measurements in 46-week-old hens that were fed mash or crumble diets differing in 50 kcal AME_n/kg during the rearing phase or diets differing in 100 kcal AME_n/kg from 17 to 46 wk of age.

In summary, the inclusion of straw in the rearing phase diets did not affect any of the egg production traits studied. However, SBP reduced egg production without affecting any other trait. The inclusion of straw or SBP in the rearing phase diets did not affect GIT development at 46 wk of age. An increase in the energy content of the laying phase diet of 100 kcal AME_n/kg reduced ADFI, improved feed efficiency, and increased BWG of the hens but did not affect any of the other production or GIT traits studied. Consequently, the ingredient composition and nutritive value of diets for pullets and laying hens can be adjusted, within the range of values studied, according to the cost of available ingredients.

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